LOW COST ATMOSPHERIC PROBE MISSIONS TO THE OUTER PLANETS

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EXTENDED ABSTRACT
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INTRODUCTION

Missions such as the atmospheric probe missions to the outer planets participate in the quest to explain the formation and evolution of the Solar System and the Earth within it. The probe missions described in this Abstract seek: understanding of the origin of the solar nebula and forces that formed Earth and the other planets; to determine the evolutionary processes that led to the diversity of Solar System bodies and the uniqueness of the planet Earth; and to use the exotic worlds of our Solar System as natural science laboratories. Broad science objectives of these missions have been set by the Solar System Exploration Road Map effort carried out by **NASA** over the past six months:

- diversity and dynamics of planetary atmospheres
- global circulation of planetary atmospheres
- bulk composition of Solar System

The key to low cost atmospheric probe missions to the outer planets is low probe mass and short flight time to the target planet. Microtechnology allows both objectives. Application of microtechnology to a Saturn Probe mission using the Cassini Orbiter for entry science data relay purposes was investigated in 1993 and 1994 (Reference 1). The material this reference was based on was prepared by the Saturn Mini-Probes Team, made up of members from Jet Propulsion Laboratory (JPL), Martin Marietta Corporation, Hughes Space & Communications Company, Ames Research Center, NASA Headquarters, University of Hawaii, and University of Arizona. That effort explored the potential to reduce probe mass and cost by an order of magnitude. The conclusion was that, given expected advances in microtechnology, such dramatic mass and cost reductions appeared feasible. The application of advanced technologies to missions to all four of the Gas Giant outer planets was subsequently initiated about a year later in an independent study carried out at JPL with the support of the JPL Advanced Projects Design Team and the NASA Outer Planet Science Working Group (OPSWG). This Paper will report on the results and conclusions from that study.

DISCUSSION

Scope

Cost drivers and technology needs were identified as objectives in the study. Mission objectives are to probe depths > 10 bars for Jupiter, > 20 bars for Saturn, and 50 to 100 bars for Uranus and Neptune, with measurements every one sixth scale height. Time history measurements of composition and atmospheric structure (pressure, temperature, and wind velocity) are required. Missions were considered with launches in the 2004 to 2010 time period with a preference shown for the potential of a low cost multi-planet mission program. Four launches over six years or less is desirable to allow heritage and low cost.

Kev Trades

Delivery mass Vs flight time is a key trade in selecting technology and constraining cost. Direct ballistic, planetary gravity-assist, and solar-electric propulsion trajectory analyses were carried out. Other trades involved science return Vs system trades, among these were: measurement profile (payload mass/cost and data rate), power requirements (probe power capability and mass), penetration depth (telecommunication trades, e.g., frequency, range, mass), and number of probes to each target planet.

RESULT-S

Trajectory Selection

The Jupiter gravity-assist opportunities for launches in 2006 and 2007 to Neptune and Uranus allowed grouping the launches for low cost and relatively short flight times: > 150 kg (single probe delivery) to Uranus and Neptune in 5.7 years and 8.6 years respectively, both launched by the Delta II (7925)/STAR 30 BP low cost launch vehicle. Shorter flight times for Jupiter and Saturn missions resulted from launches in 2004 and 2005,

Probe Payload

The OPSWG recommendation for a high science return strawman probe payload included the following instruments - the mass, power, and bits-per-sample requirements were arrived at with the help of the OPSWG, the Advanced Projects Design Team, and other members of the planetary science community:

Instrument	Mass /	Power /	Bits per Sample
- Mass Spectrometer	1.0 kg /	10 W /	50,000
Atm. Structure	0.5 kg /	3W /	200
- Solar NFR	0.5 kg /	1 W /	100
- He Abundance	0.5 kg/	1 W /	40
- Nephelometer	~ 0.5 kg /	- 3 W /	-200
O - P H2 Detector	0.5 kg /	2W /	40
(deployment mechanisms)	(0.5 kg)	-	
Total	4.0 kg /	20 W /	-50,000

Multi-Probe Program

The Table below summarizes the performance characteristics of the full four-planet program with delivery of four atmospheric probes to each target planet. The injection masses are based on full system by system designs with the range due to uncertainties in the multi-probe integration and deployment implementation

Targets	Launch	Inj Mass (kg)	Launch Vehicle	Trajectory Mode	Flight Time
Saturn	2004	310	Delta III	AVEGA	4.5 yrs
		430			4.8 yrs
Uranus	2007	299	Delta III/Star 48	Jupiter	5.5 yrs
		419		Gravity Assist	6.7 yrs
Neptune	2006	299	Delta III/Star 48	Jupiter	8.0 yrs
		419		Gravity Assist	11.0 yrs
Jupiter	2005	444	Delta II (7925)	AVEGA	.- 4.5 yrs
		540			

Costing

Both top down and bottom up cost estimates for the full four-planet (four probes to each planet') program were produced. The cost estimate came to less than $1' billion ($935 M), including: development (Phases C & D), four launch vehicles, pre-Project development (Phases A & B), and mission operations (Phase E). Potential areas for cost reduction were identified that could potentially reduce total program cost by about $100 M. The development cost (Phase C & D) per mission came to $133 M.

CONCLUSIONS

Mission, systems, and cost trade studies were performed by the JPL Advanced Projects Design Team, applying advanced technologies to reduce system mass and cost. This team also found innovative modes for achieving communications frOm great atmospheric depths, using the probe descent itself to generate electrical power by means of an aero turbine. The OPSWG defined high-value science payloads for atmospheric probes to the four Gas Giant outer planets. The resulting per mission cost for a four planet/16 probe Program is about $130 M (Phases C & D).

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The author led the mission, systems, and cost trade & design studies that resulted in the data on which most of this Paper will be based. The study members included the JPL Advanced Projects Design l-earn and members of the NASA Outer Planet Science Working Group, chaired by William B. Hubbard of the University of Arizona. Paul F. Wercinski of Ames Research Center also provided supporting consultations to me and the JPL Advanced Projects Design Team on probe aerothermodynarnics.

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REFERENCE

1. "Saturn Probe, Science & Engineering Feasibility", R. A. Wallace, et al, Paper No. 0403P, IAA International Conference on Low Cost Planetary Missions; Laurel, Maryland; April 12 through 15, 1994.